AL/CF-TR-1994-0113

A R M S T R O N G   L A B O R A T O R Y

TOOLS FOR AUTOMATED KNOWLEDGE ENGINEERING (TAKE) SYSTEM EVALUATION METHODOLOGY (U)

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JUNE 1994

INTERIM REPORT FOR THE PERIOD DECEMBER 1993 - JUNE 1994

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AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-7022

NOTICES

TECHNICAL REVIEW AND APPROVAL

AL/CF-TR-1994-0113

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

William T. Wittman

for **KENNETH R. BOFF**, Chief
Human Engineering Division
Armstrong Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
June 1994

3. REPORT TYPE AND DATES COVERED
Interim December 1993-June 1994

4. TITLE AND SUBTITLE
Tools for Automated Knowledge Engineering (TAKE)
System Evaluation Methodology

5. FUNDING NUMBERS
C: F41624-94-D-6000
PE: 62202F
PR: 1784
TA: 10
WU: 44

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Logicon Technical Services, Inc.
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory, Crew Systems Directorate
Human Engineering Division
Human Systems Center
Air Force Materiel Command
Wright-Patterson AFB, OH 45433-7022

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/CF-TR-1994-0113

11. SUPPLEMENTARY NOTES
*Logicon Technical Services, Inc.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This paper describes the methodology in which the Tools for Automated Knowledge Engineering (TAKE) software application has been used to conduct various military human-system interface evaluations. The TAKE methodology involves collecting relevant information through a knowledge elicitation technique known as "Concept Mapping." Concept Mapping is more "user-oriented" than other techniques such as written questionnaires or oral interviews. The information is more useful because its medium of communication ensures an accurate portrayal of the system, as viewed by the user, unbiased by any preconceived notions of the questionnaire author or interviewer. TAKE consists of several knowledge engineering tools. These include the capability to draw, copy, edit, save and print concept maps for user-specified information. Armstrong Laboratory has used TAKE within the context of the described methodology for the evaluation and/or design/redesign of various military human-system interfaces.

14. SUBJECT TERMS
Knowledge Acquisition, Knowledge Engineering, Concept Mapping, Concepts, Systems Analysis, Systems Design, User Requirements, Human Factors, Domain Expert

15. NUMBER OF PAGES
37

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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SUMMARY

This paper describes the methodology in which the Tools for Automated Knowledge Engineering (TAKE) software application has been used to conduct various military human-system interface evaluations. TAKE is a prototype computer software package developed and designed by Armstrong Laboratories to elicit, record and analyze information used in system evaluations.

The TAKE methodology involves collecting relevant information through a knowledge elicitation technique known as "Concept Mapping." Concept Mapping is more "user-oriented" than other techniques such as written questionnaires or oral interviews. The information collected through Concept Mapping is more useful because its shared medium of communication ensures an accurate portrayal of the system, as viewed by the user, unbiased by any preconceived notions of the questionnaire author or interviewer.

TAKE consists of several knowledge engineering tools. These include the capability to draw, copy, edit, save and print concept maps, to produce hierarchical outlines of concept maps and to use customized subject categories to search one or more concept maps for user-specified information. Armstrong Laboratory has used TAKE within the context of the described methodology for the evaluation and/or design/redesign of various military, human-system interfaces. Applications for TAKE can also include the evaluation of industrial workplaces, artificial intelligence systems and other human-system interfaces.

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INTRODUCTION

This paper describes the Tools for Automated Knowledge Engineering (TAKE) methodology used by certain personnel at Armstrong Laboratory for evaluation and design/redesign of various military, human-system interfaces. This methodology can, however, be applied to the evaluation and design/redesign of any type of system. The main difference between the TAKE methodology and other previous methodologies lies in the type of knowledge elicitation techniques and computer analysis tools that are utilized.

Typical Knowledge Acquisition in System Evaluation

The first step in the evaluation of any system is acquiring the information about a system that will enable one to effectively perform the evaluation. The sources of such information include reference documents, system diagrams and domain experts (DE's) (experienced system users). Eliciting information from domain experts typically involves asking system related questions in a personal interview or through a written questionnaire. The questions asked of the domain expert are usually derived from the viewpoint of the system evaluator and as such, are biased in that direction.

Previous research has shown that certain constraints can be placed on knowledge acquisition by the types of probes made by the knowledge engineer (Perfetto, Bransford, & Franks, 1983; Adams, Kasserman, Yearwood, Perfetto, Bransford, & Franks, 1988). The information acquired can be limited by preconceived, closed end questions asked of the domain expert. Knowledge acquisition methods produce more information when they use open ended questions (if questions are used at all) that are not biased by the elicitor's preconceived ideas about the system. These questions are "product-oriented" and not "product-user-oriented." (See Zaff, McNeese and Snyder, 1991, for a more detailed discussion).

In contrast, user-oriented or "user-centered" knowledge acquisition focuses on the system user when developing the knowledge acquisition strategy. This allows the user to provide system information in a manner which is most comfortable for the user. Supplying the user with an open-ended, free flowing format for providing his/her expert knowledge increases the chances of the user providing the most relevant and/or important information for the system evaluation. The expert knowledge acquired is viewed as important by the user and, as such, is usually

extremely relevant to the system evaluation. An open-ended format also provides the user with the opportunity to offer feedback to the interviewer on the accuracy of the interviewer's interpretation of what the user is saying. This is not possible when completing a verbal or written questionnaire. Therefore, user-centered knowledge acquisition could be defined as: 1) involving a methodology that facilitates flexible access of information, 2) providing a medium for shared communications, and 3) involving procedures which are compatible with the way that the domain expert thinks about his/her system.

A knowledge acquisition technique which satisfies the definition of user-centered knowledge acquisition is "Concept Mapping." The TAKE system evaluation process utilizes concept mapping to capture information collected from domain experts. Concept mapping proved to be a superb knowledge acquisition technique for design during the development of the Advanced Knowledge and Design Acquisition Methodology (AKADAM) (McNeese, Zaff, Peio, Snyder, Duncan & McFarren, 1990). TAKE was created from the ideas generated and the knowledge gained while utilizing AKADAM. TAKE applies concept mapping to create integrated knowledge databases that are then analyzed with computer assistance to distill and extract information that allows the human factors engineer to develop sound human-machine interfaces.

Concept Mapping

Concept mapping is a technique where textual or verbal information is collected and graphically represented in the form of interconnected concept elements. These concept elements are connected by links which represent the relationships between the different concepts (concept-relationship-concept). See Figure 1 for a graphic depiction of a concept-relationship-concept "triple." The concepts are typically represented by ovals (nodes) and the relationships by uni-directional arrows (links).

Concept mapping is intended as a means of collecting and visually representing different pieces of knowledge or information about a particular topic and how those pieces of information are interconnected. Concept mapping is often used as a learning tool, to graphically portray both general and specific concept knowledge. The technique is easy to use and avoids strict rule sets associated with more "structured" analysis techniques (Snyder, McNeese and Zaff, 1991). See Figure 2 below for an example of a small concept map of some of the advantages of concept mapping.

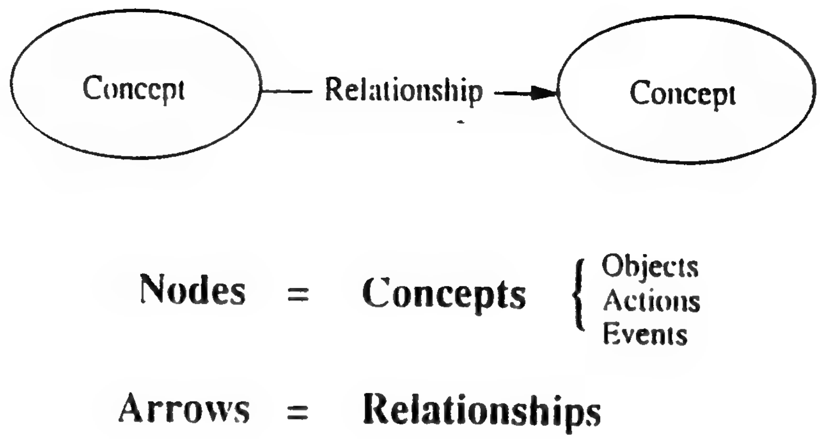

Figure 1. Example of a Concept-Relationship-Concept "triple."

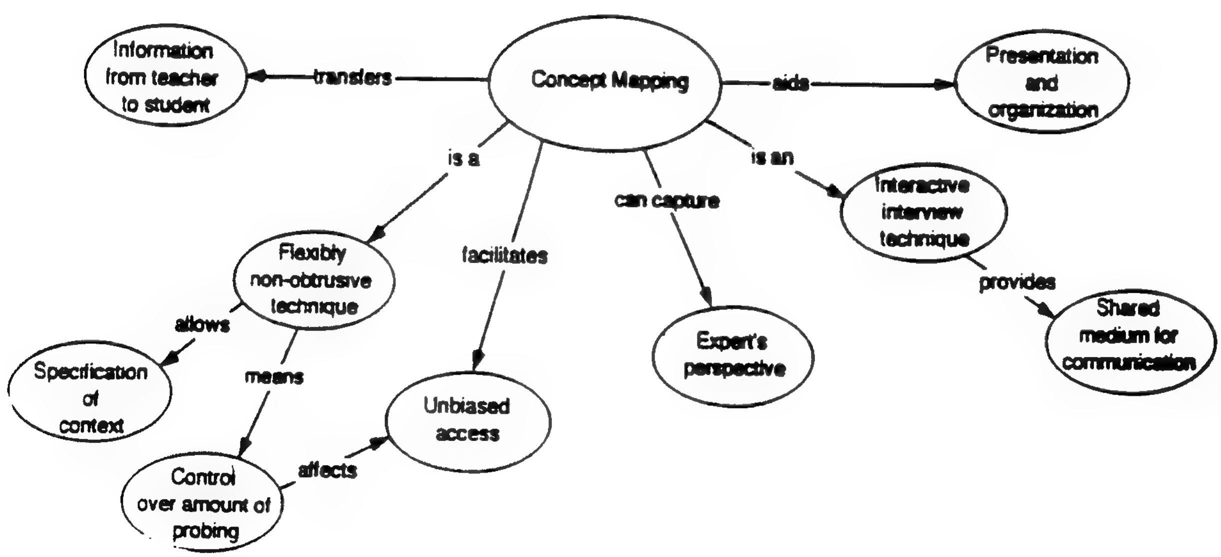

Figure 2. Example of a concept map.

User-centered knowledge acquisition involves a methodology that facilitates flexible access of information. Concept mapping fulfills this requirement. When a domain expert is "mapped," they are able to free associate on a particular system, it's characteristics, performance attributes, shortcomings, strengths and/or idiosyncrasies. No matter what the system attribute is, it and all of its inter-relations can be accurately represented in a concept map.

User-oriented knowledge acquisition also provides a medium for shared communications. A shared medium for communications allows the conveyor of the information to see what the recipient of the information has comprehended and how it is interpreted. A shared medium of communication is not provided for in the usual personal interview of domain experts. This is because it does not allow all parties to know and track the interpretations of the knowledge engineer. The visual representation of expert knowledge through interconnecting concepts linked by relationships, provides an excellent medium for shared communications. In the concept map, the domain expert can literally see the knowledge engineer's perception of the system concepts and their respective inter-relationships and can therefore make corrections to the map, if necessary.

Additionally, user-centered knowledge acquisition requires that the knowledge acquisition procedures be compatible with the way the domain expert thinks about his/her system. This is accomplished by using both structured (e.g. questionnaire type) and unstructured (e.g. concept maps) techniques. This has the benefit of eliciting a broad and deep range of information from the domain expert while also satisfying the structured information requirements of the system engineers, programmers and designers.

Tools for Automated Knowledge Engineering (TAKE)

TAKE is a prototype computer software package developed at Armstrong Laboratories which is designed to analyze information contained in concept maps. In addition to providing concept map drawing and storage capabilities, TAKE possesses several knowledge engineering tools. These include the capability to a) build outlines of concept maps, b) facilitate creation of user-defined categories of key words and c) search one or more concept maps for the key-word-related information.

The drawing capability enables the user to enter and store a graphics

file of a concept map. The concepts can be graphically represented by several different shapes (ovals are the default shape). These are typically referred to as "nodes." The relationships between the concepts are graphically represented by arrows extending from one concept to another. The arrows are referred to as "links." Concept and link labels can be easily assigned or edited simply by clicking onto the label with a mouse or trackball device and then inputting the label name into a field via keyboard entries. These labels serve to describe the concepts and the relationship between them.

Concepts and links can be created or deleted with single keyboard input commands. Multiple concepts can be linked together. The position of one or more concepts within a map can be changed by clicking onto the concept(s) and dragging it (them) to the desired position. The default map size is one standard size piece of paper (8.5 x 11 in.) but can be increased to up to approximately 100 (10 x 10) pages.

TAKE is capable of organizing the concept map information into a data base, from which outlines can be created and keyword searches made. An outline consists of a listing of all the concept-relationship-concept triples in a top-down hierarchical order. This order emulates the top-down order of the concept map. An example of an outline is shown in Figure 3. The outlines can be used to support HSI analyses by grouping information into logical clusters. This feature is useful in generating functional decompositions and in organizing large scale data bases. An ASCII file of the outline can be exported for use in a word processor or for further data analyses.

Source Node	Link	Destination Node
Task 1	*req*	Controls
Controls	*include*	CDU
Controls	*include*	Throttle
Task 1	*req*	Displays
Displays	*include*	CDU
Displays	*include*	FLIR
Task 1	*has*	Workload
Workload	*equal to*	High
Task 1	*has*	Frequency
Frequency	*of*	2
Task 1	*has*	Criticality
Criticality	*equal to*	Medium

Figure 3. Example of a concept map outline.

TAKE can also be used to index the concept map with "context slices." Context slices are categories of information identified by a set of key words. The key words can be used to search for specific types of information related to the goals of the analysis. Key words are assigned, by the analyst, to each of several categories. The information within the concept map can be easily categorized for problem identification, task assignments or other characterization.

Categories such as "visual," "temporal," "spatial," "resources," "requirements" and "differences" have been used in previous analyses. Key words assigned to the "visual" category included anything that dealt with the human processing of visual information, e.g. "see," "look," "NVG," "glare." The map data base is searched for the core components of each key word and any concept-relationship-concept triple containing these components is listed. The results of the keyword search can be printed and/or stored in a file under a filename of the user's choice. Later the file can be accessed simply by clicking on to the category name in the category create/edit window. An infinite number of categories of information can be created and/or combined.

The categories of information can also be color coded. This allows one to quickly locate specific topic areas in the map. Combinations of categories may be created which can aid in the determination of very specific problem areas such as "visual limitations" or "anthropometric limitations." Figure 4 contains the "Categories" window in which the keyword search operations are performed.

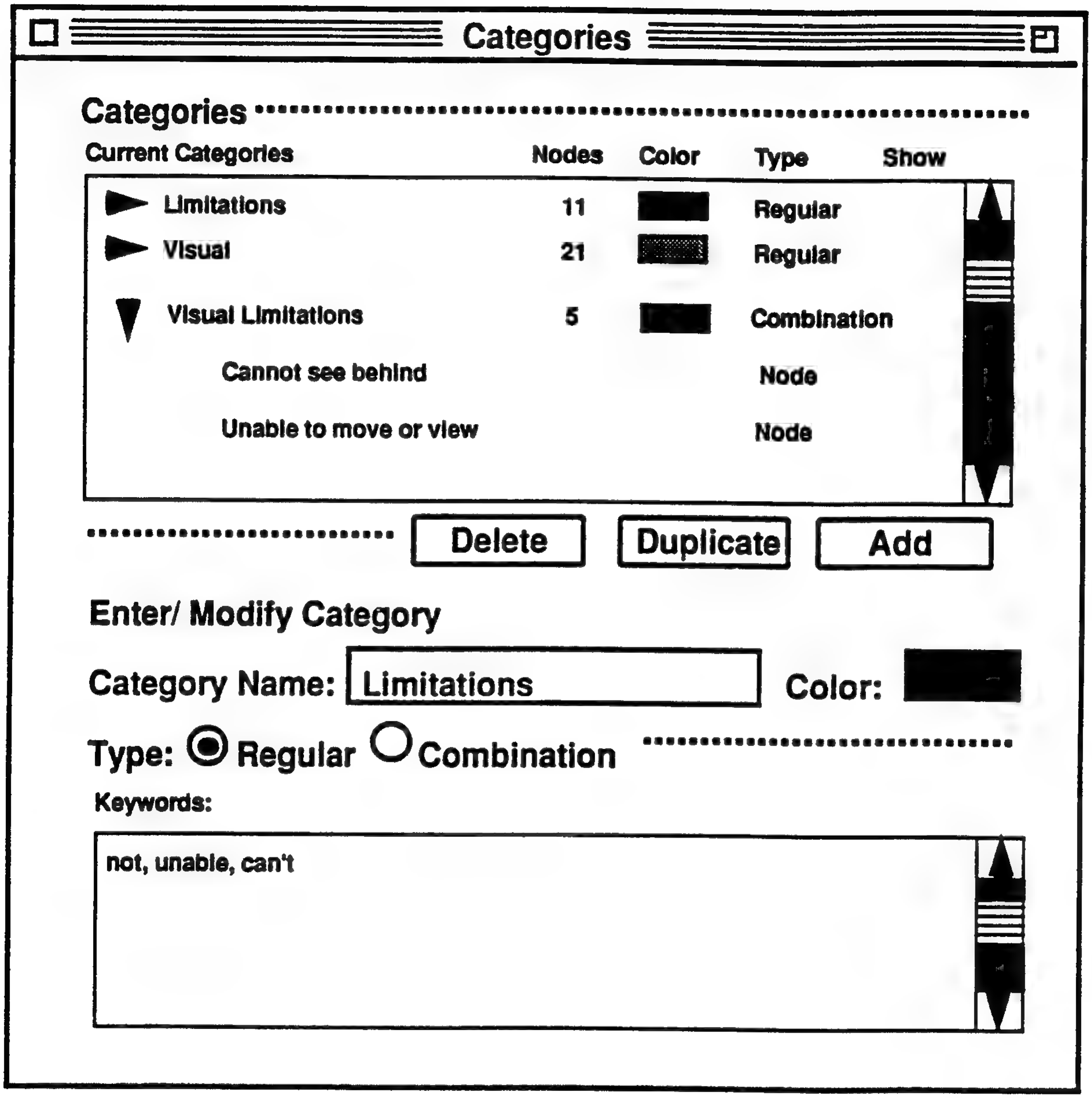

Figure 4. TAKE "Categories" create/edit window.

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METHODOLOGY DESCRIPTION

The TAKE methodology is graphically depicted in Figure 5. There are eight basic groups of activity which are somewhat, but not exclusively, sequential in nature. These steps are also not all strictly physical activities. Some steps involve cognitive analyses that are ongoing, yet transparent to the outside observer.

Identification of System/Mission Objectives

The system/ mission objectives are typically provided by the group in need of the system evaluation in the form of text reference material or through a personal interview. These objectives, however, can also be acquired by concept mapping various senior system/mission experts. The process of acquiring the system/mission objectives is graphically depicted in Figure 6.

Identification of System Operations/Mission Profile

The process of identifying the system operations or mission profile involves four activities which are shown in Figure 7 and described below.

1. Identification of Senior Domain Expert -Identification of a Senior Domain Expert(s) (SDE) is performed through consultation with the point of contact or high ranking official of the organization requesting the human-system interface evaluation/redesign. The senior domain expert(s) is typically that person possessing the most experience operating the system being evaluated. They should be intimately familiar with all scenarios within which the system operates and the system performance requirements in those scenarios.

2. System Operation/Mission Profile Acquisition - A description of the system operation or in the case of a military aircraft, the mission profile, is obtained through an in-depth interview with the senior domain expert(s). The SDE is asked to describe the system operating scenarios and the mission to be accomplished. The information is recorded on audio tape and is drawn on a large white/black board in concept map form. This provides immediate feedback to the SDE on the interviewer's interpretation of the information provided by the SDE. The concept map is entered into a computer via the TAKE software for later analysis and hard copy printout.

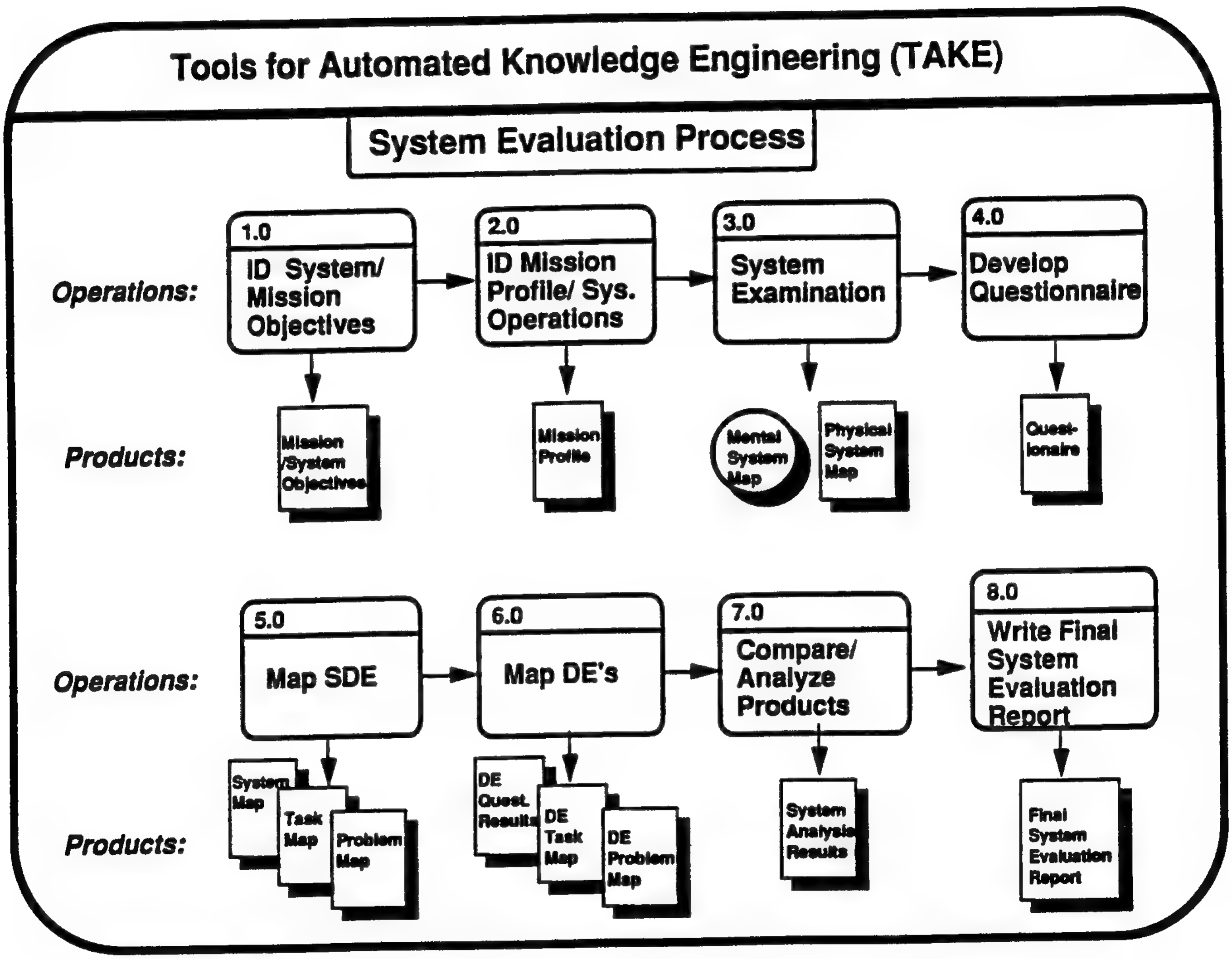

Figure 5. TAKE System Evaluation/Redesign Methodology.

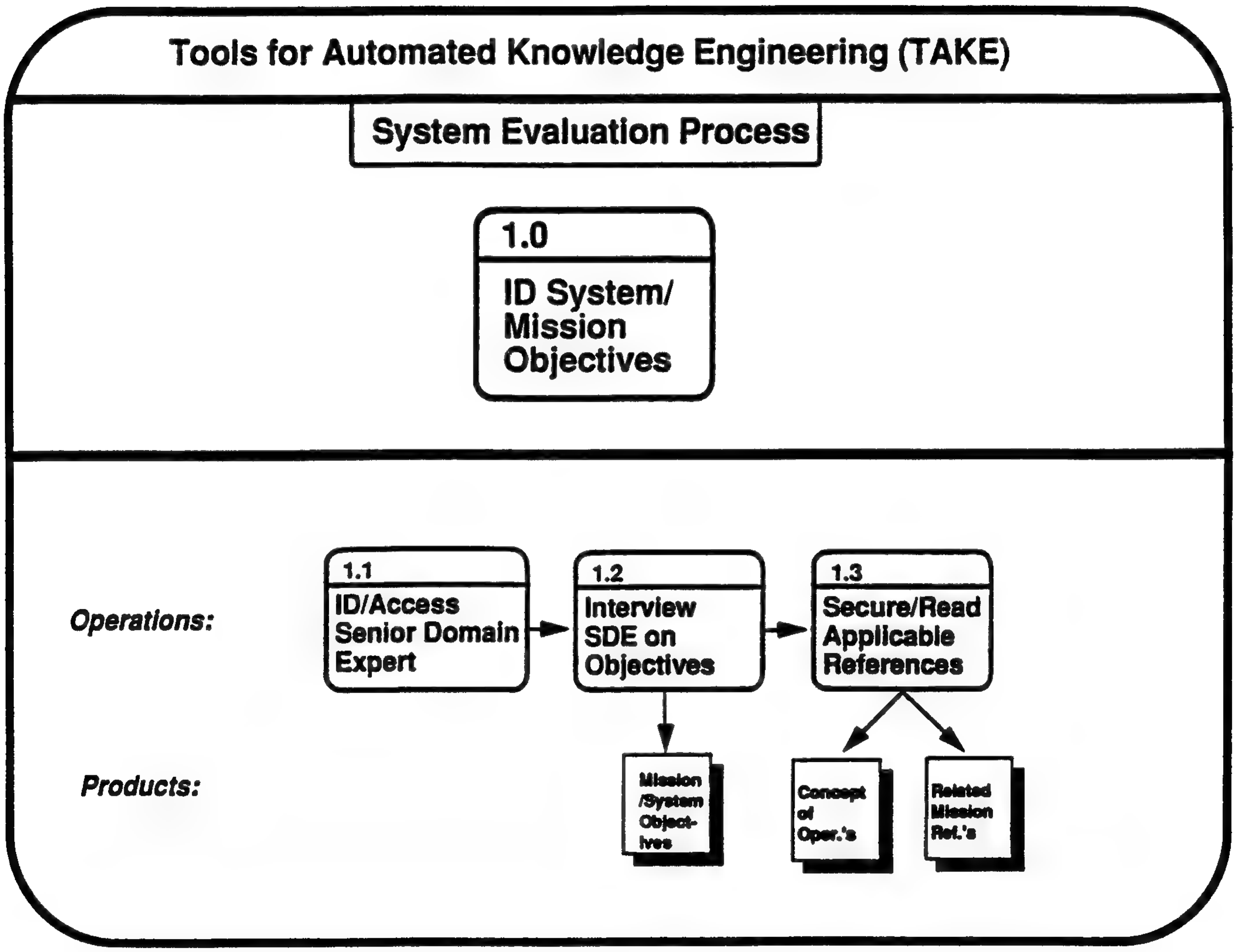

Figure 6. Identification of System/Mission Objectives.

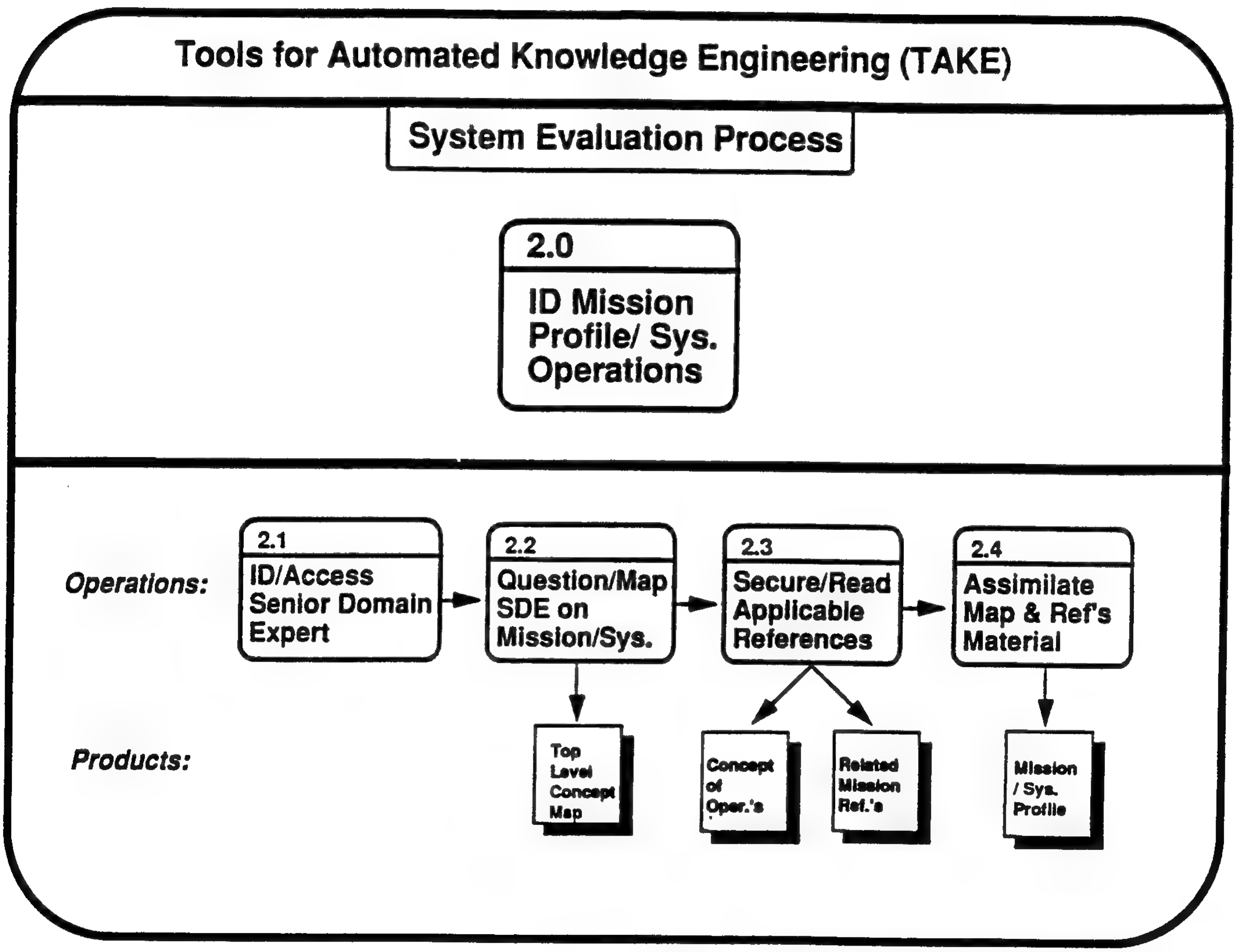

Figure 7. Identification of System Operations/Mission Profile.

3. Reference Material Acquisition - Reference materials describing the system operations or mission profile are collected. More specifically, documents such as the User's Manuals, Statement of Operational Need (SON), Concept of Operations (CONOPS), Technical Orders (TOs) and mission requirements lists are collected. This is done through comprehensive, multi-database literature searches and solicitation of SDEs for applicable reference materials.

4. Concept Map & Reference Material Assimilation - System evaluation/redesign personnel study and assimilate collected reference materials and the system operation/mission profile concept map collected from the SDE.

System Hardware Examination

The system being evaluated is examined and its physical dimensions and characteristics are assimilated. The following are three activities which are performed collectively or individually to develop a cognitive or mental map of the system hardware and its human-system interface (HSI). This process is graphically summarized in Figure 8.

1. System Reference Material Acquisition - Reference materials describing the physical make-up of the system are acquired through comprehensive, multi-database literature searches. Documents may include User's/Reference Manuals, Technical Orders and updates, mission checklists, human factors and engineering research reports on various system related topics and diagrams and/or drawings of the system and its HSI.

2. System Reference Material Examination - Using the reference materials the system evaluation personnel familiarize themselves with the system's controls, displays, anthropometric characteristics, overall layout, system personnel staffing and assigned and unassigned tasks.

3. Personal or Vicarious System Interaction - System evaluation personnel should always attempt to gain some experience operating the targeted system or a relatively high fidelity system simulator. If this is not possible, then they should observe and/or videotape trained system users operating the system in typical system operating scenarios.

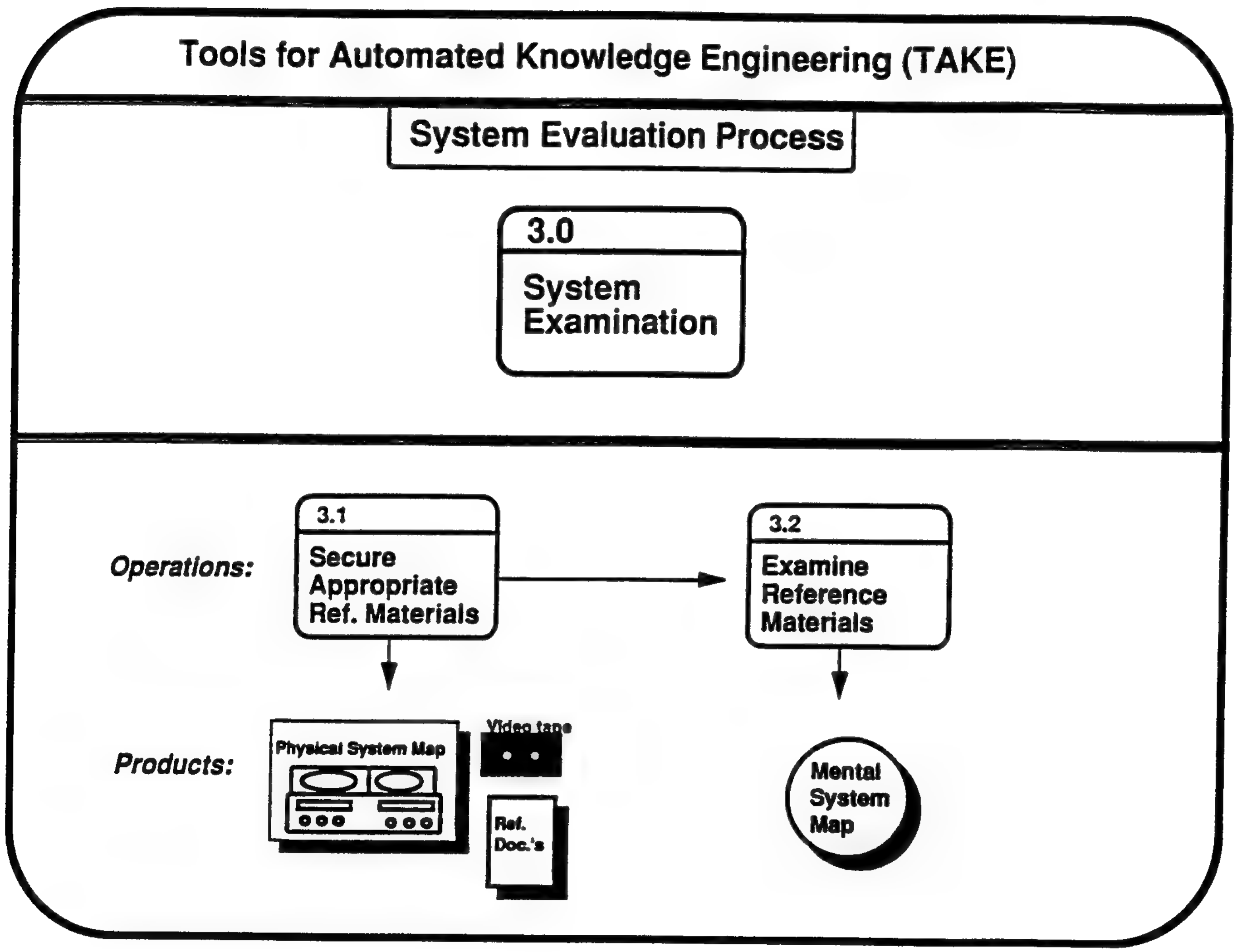

Figure 8. System Hardware Examination.

Questionnaire Development

A questionnaire is developed to elicit information which may be of value in improving the HSI but which may not be volunteered by the DE(s). This information is often associated with areas in which the DE is not even aware of an existing problem. For example, a DE may not know that replacement of the digital readouts for several system states with analog representations will reduce his/her workload. Therefore, a DE may not volunteer this information. However, a properly designed questionnaire will reveal the fact that the HSI in question is limited to digital readouts only, thus clearing the way for future HSI improvements in this area. This process is described below and shown in Figure 9.

1. Acquisition of Similar System Evaluation - Obtain (through literature searches and personal contact with field-specific professionals) references reporting evaluations of systems similar to the targeted system. These references should contain questionnaires used in the evaluations which can be used as models for the present questionnaire. Reviewing several questionnaires will provide the system evaluation personnel with an ample number of examples from which to choose for inclusion in their own system evaluation questionnaire.

2. New Question Identification - Review system operation and physical description references for material not addressed in similar system evaluation questionnaires. Questions should address functional grouping, visibility, anthropometric reach envelope compatibility, comfort, fatigue, task workload, user acceptance, etc. of the system interface.

Senior Domain Expert Mapping

Several maps are created representing different areas of the SDE's expertise. The process of collecting and mapping this information is shown in Figure 10 and described below.

1. SDE Concept Map Acquisition - The senior domain expert is concept mapped to elicit all the system, task and problem data known to him/her. This includes eliciting all the knowledge he/she has on the total operational system, the scenarios in which it operates, all the tasks/functions it must perform, the interface design and the problems associated with any aspect of the system. Mapping the SDE is usually an iterative process. A top level map may first be taken and then broken down into subcomponents at later mapping sessions.

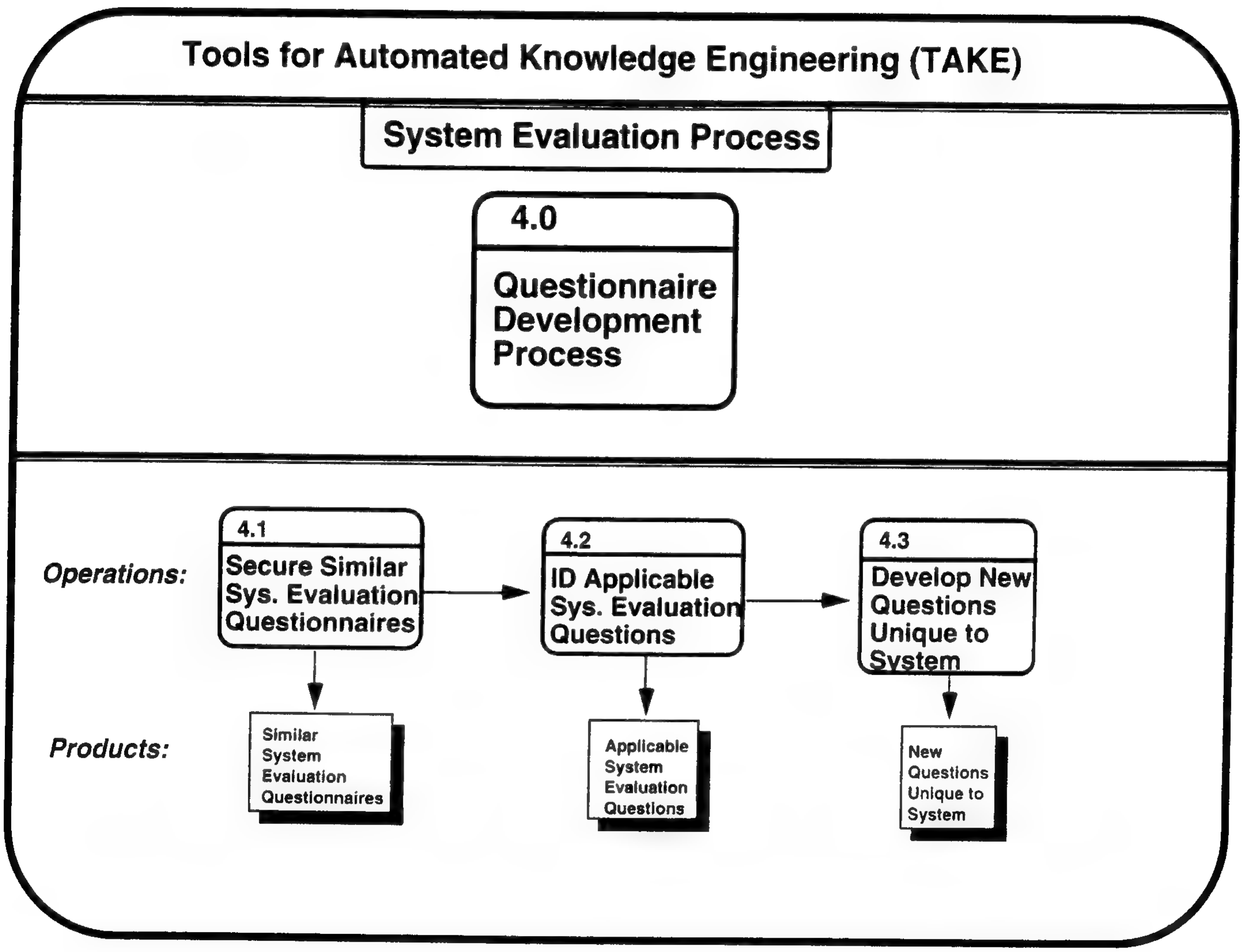

Figure 9. Questionnaire Development Process.

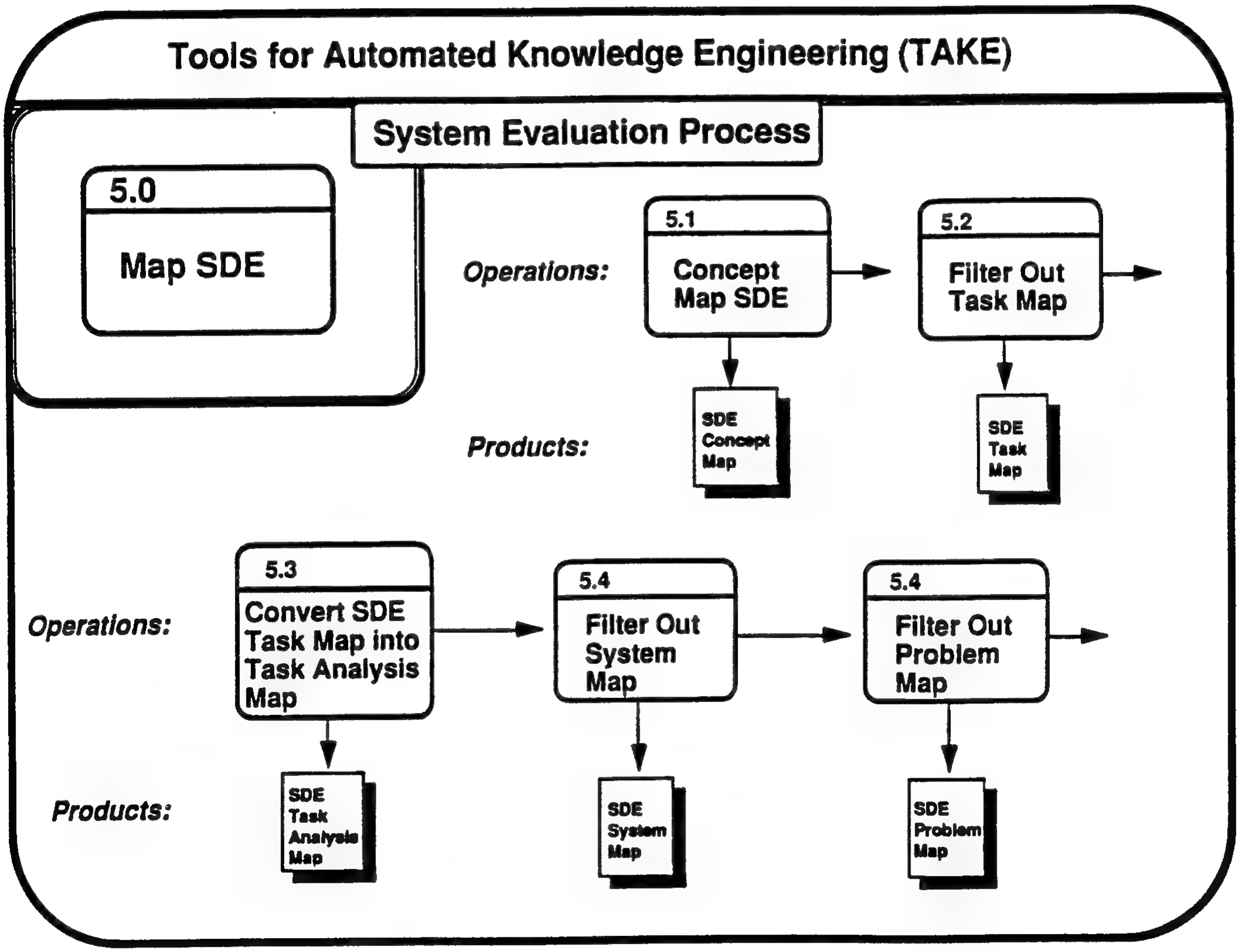

Figure 10. Concept Mapping of the Senior Domain Expert.

2. Task Map Acquisition - A concept map of all personnel tasks is elicited from the SDE for the purpose of conducting a task analysis later. This map resembles a timeline in that the tasks are usually sequential in nature. It is only necessary to describe the tasks globally here because more detail will be obtained from the DEs.

3. Task Map Conversion - Specific "nodes of inquiry" can be added to the task map for the purpose of eliciting specific information from domain experts on certain aspects of their respective tasks. For each task node there are a pre-set group of nodes that can be attached to it. These include nodes representing the controls, displays, task frequency, criticality and workload ratings and known problems with the interface design or with completing the task. The new map is called the "task analysis map."

Collecting data for task workload, criticality and frequency and displays and controls satisfaction in the concept map format combines the best of two worlds for a comprehensive evaluation and analysis. The DE system task analysis map provides valuable qualitative data regarding the domain expert's relationship with the system along with the quantitative data necessary for conducting traditional task analyses and workload assessments. A scaled down version of a generic "task map" is shown in Figure 11.

4. System Map Acquisition - A concept map of the system hardware is gleaned from the SDE map by the analysis team for later comparison with system hardware diagrams and descriptions.

5. Problem Map Acquisition - A concept map of the SDE's perceived problems with the system is gleaned from the SDE map. This map will be used later to query DEs either in a group or individually. The map will be used to solicit further details on the SDE's perceived system problems.

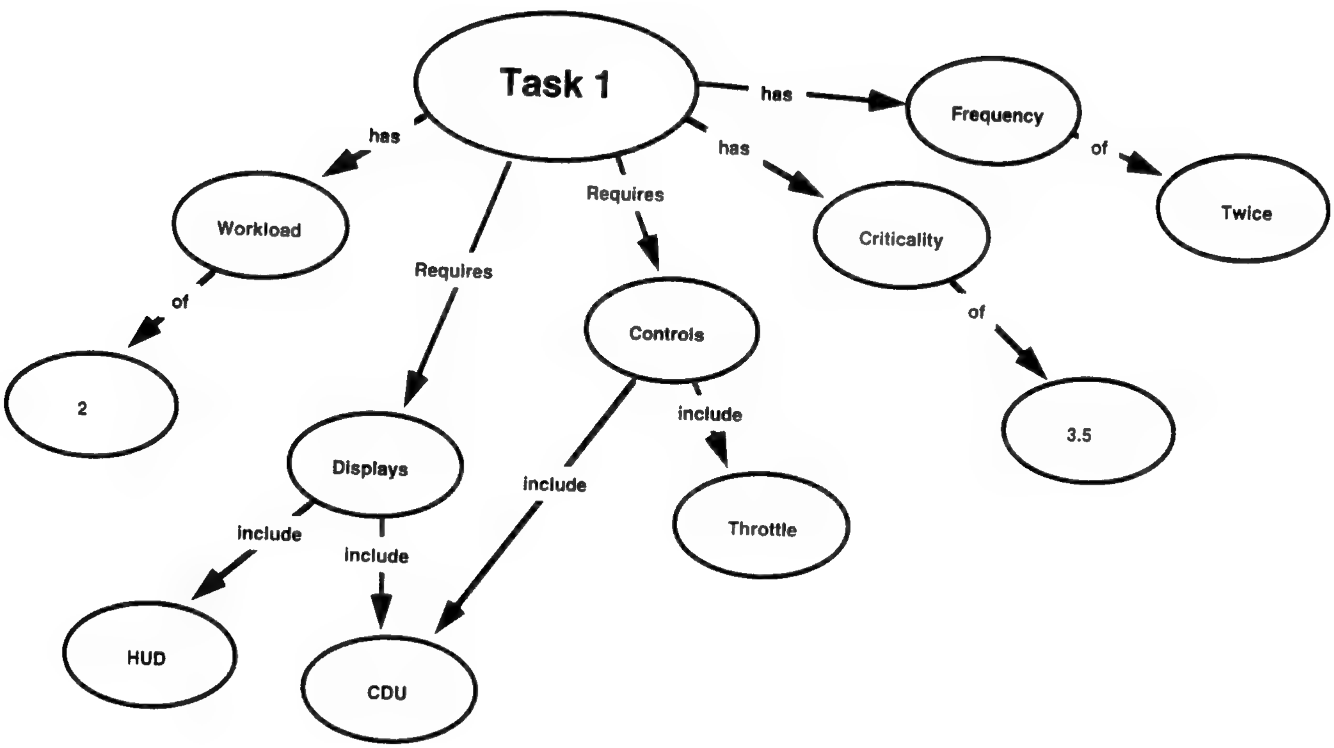

Figure 11. Scaled Down Example of the Task Map.

Domain Expert Mapping

Individual interviews are conducted with as many domain experts as possible. In these interviews a system interface questionnaire is administered, and a task map and a problem map are acquired. This process is shown in Figure 12.

1. DE System Task Map Acquisition - The section of the DE map describing a domain expert's main tasks will have already been outlined in the senior domain expert's map. The top level tasks provided by the SDE will provide an outline for a more detailed map which all DEs will expound upon. The DE's are asked to provide, in an individual interview, specific details concerning the following: a detailed description of each of the subtasks associated with the main tasks outlined by the SDE, a description of how he/she performs each of the tasks/subtasks outlined by the senior domain expert, a workload rating associated with each task, the frequency of each task, the criticality of successful completion of each task, the displays and controls used on each task, how and why they are used in each task, a satisfaction rating for each set of displays and controls, and any problems associated with performing one's tasks and the system interface used on that task. Mapping the DE, as with the SDE, is an iterative process that may and often does require more than one mapping session

2. DE System Problem Map Acquisition - A group of DEs is assembled for the purpose of collecting system interface problem data in concept map form. Some system interface problem data is elicited in the process of constructing the DE system task map. However, the group mapping process has proven advantageous in that the problems reported by a single group member often trigger the recall of other problems encountered by other group members. Some of these problems may not be recalled in the individual interview. The group interview/mapping session may also produce interface preference data and possible solutions to reported problems.

3. DE Questionnaire Administration - Questionnaires are administered to as many DEs as possible. The questionnaires address specific system interface areas of interest to the analysis team. These areas may be ones which escape the attention of the DEs during task and problem map construction or ones which the DEs consider to be satisfactory but, in fact, are good sources for possible improvement.

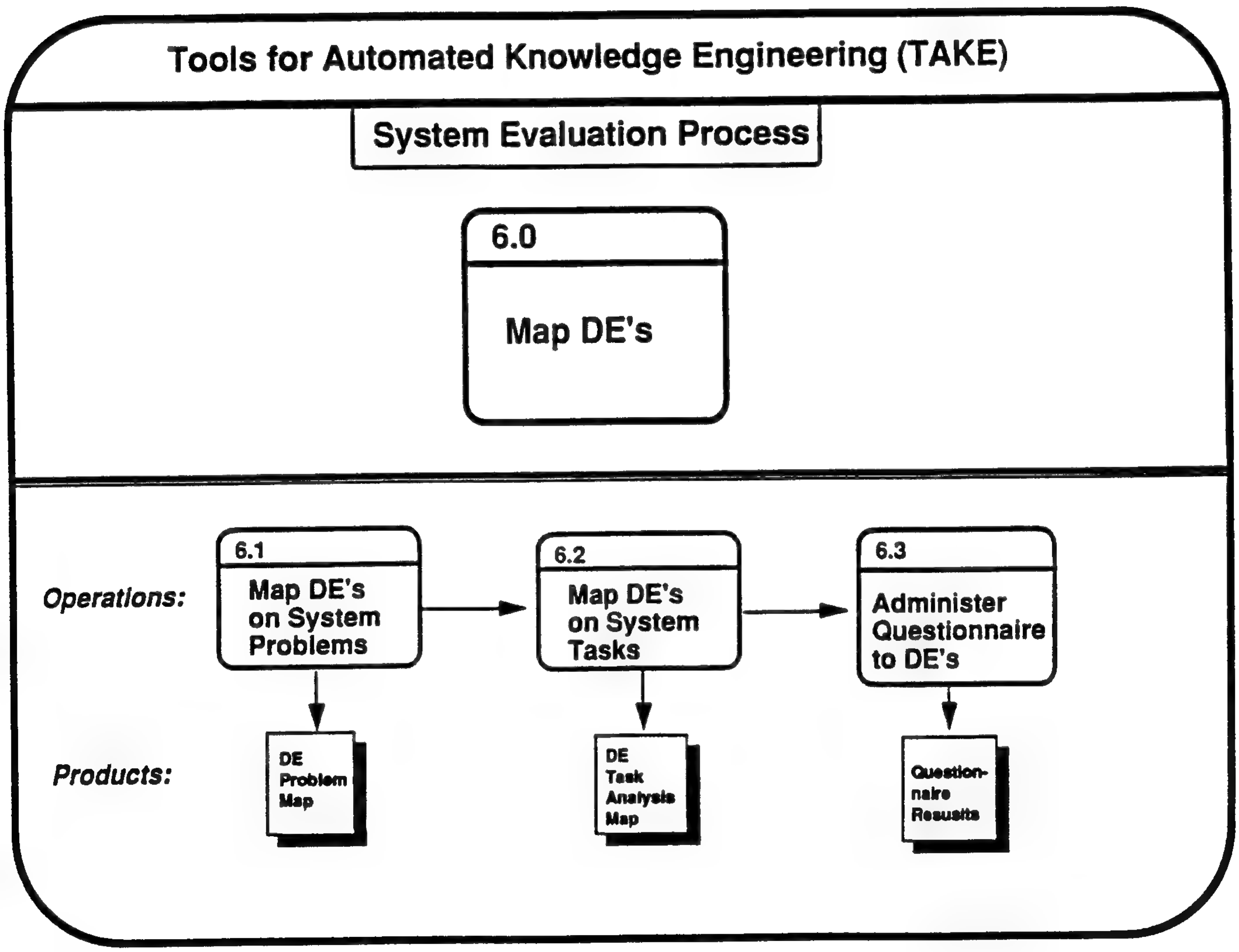

Figure 12. Concept Mapping of the Domain Expert.

Data/Product Analysis

The data analysis step of the system evaluation process involves comparing and analyzing the products of the previous steps (the reference materials, the system diagrams, the different concept maps, the questionnaire results, etc.). This step in the system evaluation process is shown in Figure 13.

In making the following comparisons and analyses the analysis team looks for examples of poor to fair interface design and/or tasks characterized by medium to high workload levels. Once the interface and/or workload problems are identified, possible solutions are formulated. The formulated solutions are subjected to formal or informal cost/benefit analyses to determine their respective feasibility.

1. System hardware vs. SDE System Map Comparison - This step is not so conscious as it is unconscious. This step is carried out mentally throughout the evaluation process where the analysis team is continually making mental comparisons between the SDE's perception of the system hardware and the actual system hardware. Differences between the two can be rooted in the interface design. The differences need to be identified and addressed by the analysis team.

2. Human Factors Guideline Compliance Check - The system hardware is thoroughly checked to make sure all displays and controls conform to known human factors interface design principles. These principles are discussed and/or presented in several different references such as MIL-STD-46855, MIL-STD-203, MIL-STD-1333, MIL-STD-1472D, AFSC Design Handbook 1-3;2-2, The Handbook of Perception and Human Performance and the Human Engineering Guide to Equipment Design.

In practice, most systems are not in total compliance with all of the known human factors guidelines. The reasons for this are usually mitigating circumstances particular to a specific system. These circumstances are examined to verify that there are no viable alternatives which would bring the system into guideline compliance. The objective is not to bring the system into compliance for compliance's sake but to make the system as user-friendly as possible within the existing monetary and time constraints. An accumulation of small guideline infractions can steadily increase workload to the point of causing one or more critical errors due to operator overload. Therefore, this will hopefully prevent an accumulation of minor guideline infractions from turning into a major human factors system problem.

3. SDE & DE Problem Examination - This step is characterized by the documentation of specific problems identified by the SDE and DE's in their respective system and problem maps. This can be accomplished by TAKE's "outline" function or TAKE's key-word search capability. Problems reported by the SDEs and DEs can either be identified in the map outline or found through the creation of "categories" of key-words and the automated search for specific information related to those "categories". Problems related to the "categories" will be color-coded in the map(s) and therefore, quite easily identified. Possible human factors solutions involving system interface changes or task automation are formulated and discussed by the analysis team. Several factors affecting the determination of any optimal system interface or automation changes are considered. These include the system hardware, the task frequency, workload and criticality ratings, the "control display unit" software architecture or design and the overall interface design or layout.

4. Questionnaire Analysis - The questionnaires are analyzed to determine the salient opinions of the system interface users in order to pinpoint serious problems with the interface which may have escaped the attention of the SDE's or DE's in the generation of the problem and system maps. Statistical analyses can be applied to the subjective ratings to determine the most critical or serious interface subsystem or task problems and/or the subsystems or tasks which are rated as most satisfactory by the users. Once the most critical problem areas are determined they can be studied for possible solutions. Factors affecting possible solutions to problems identified in the questionnaire are listed above in the section describing the SDE and DE problem examination process.

5. Analysis of Task Analysis Map - First, an analysis is conducted on the workload data collected in each DE system map to determine the respective workload of each crew member's tasks. The mean frequency and criticality rating of each task can also be computed. The workload, frequency and criticality data are then compared to determine which tasks or task combinations are good candidates for reassignment to other crew members or for automation. The displays and controls used for each high workload task are also evaluated for possible human factors improvements. Again, the TAKE key-word search capability can be utilized to ferret out problematic task workload, frequency and criticality data. This is especially helpful when dealing with very large task maps.

6. Human Factors Guidelines & Problem Map Comparison - Each problem in the problem maps/list is examined for possible violations of documented human factors interface design principles. Solutions to guideline violations are formulated, discussed and implemented where possible. Again, the aforementioned factors which affect the implementation of possible solutions are listed in the section above concerning SDE and DE problem examination.

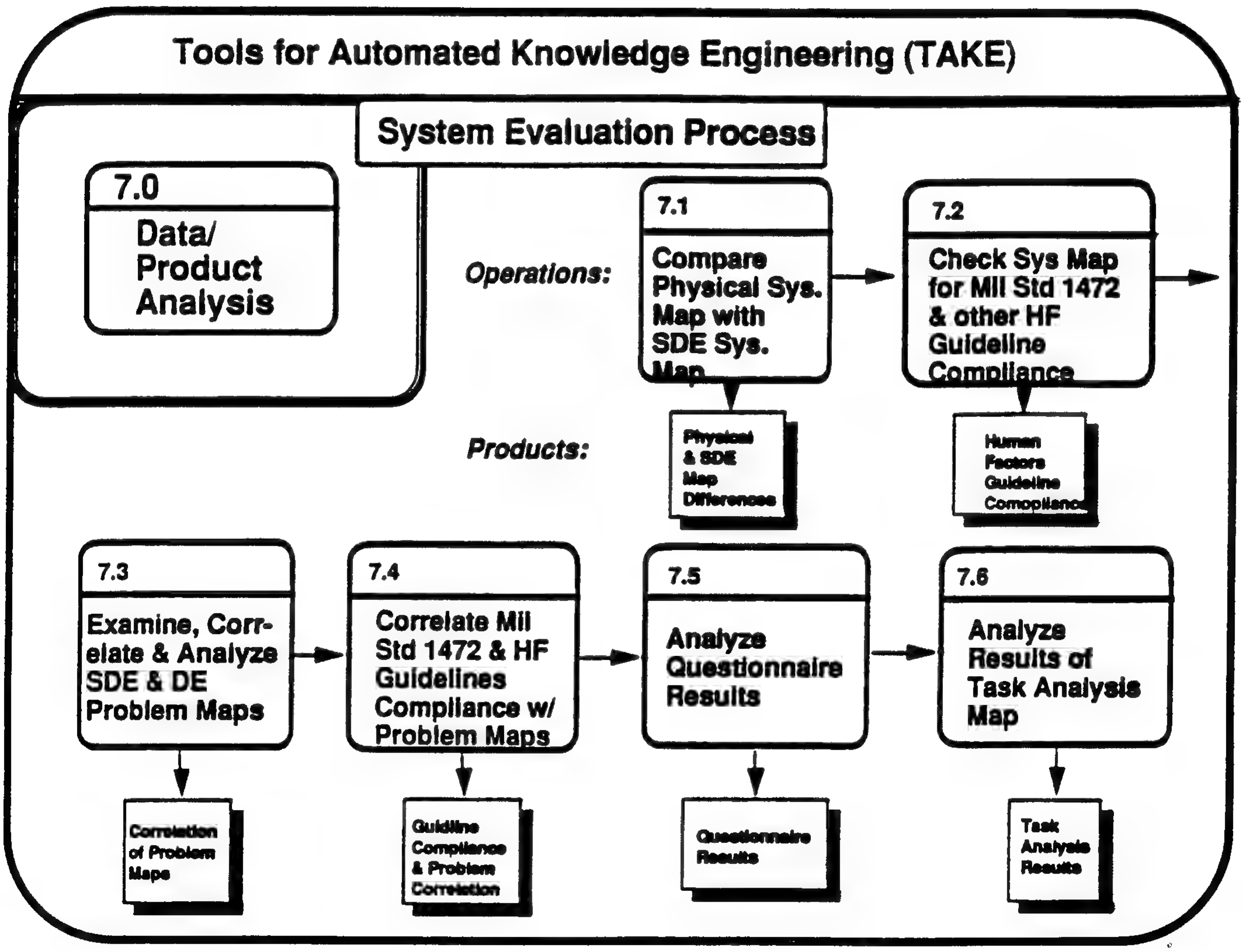

Figure 13. Data Analysis Process.

7. Final Product/System Analysis - A formal or informal cost/benefit trade-off study can be conducted to determine how many of the identified problems can be solved. The relative criticality or severity level of each problem is estimated by the analysis team based on information contained in the SDE and DE problem maps. The severity of each problem, the time and money costs and the payoff of different possible solutions are then compared. It is then determined at which point one can implement interface changes as solutions to the identified problems. This analysis is often conducted in an informal manner through discussion and the use of reference materials.

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CONCLUSIONS

The TAKE methodology has proven to be a sound, effective process for conducting evaluations of human-system interfaces. Its strengths lie in its ability to a) elicit system-related knowledge or information from system experts or users and b) organize that information in a manner which is conducive to logical analysis. The TAKE methodology lends itself to different problem solving approaches. An individual user's approach to mapping the source of the system information should be based on the goals of the evaluation. Therefore, the focus of and the amount or type of organization imposed upon the map is determined by both the mapper and the system itself. This flexibility gives the TAKE tool immense power and an infinite number of applications.

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U. S. Government Printing Office 1995 650-075/00047